Technological Status and Market Trends of Photovoltaic Cell Industry

İRFAN GÜNEY

Engineering Faculty, Department of Electrical Engineering
Acıbadem University
İnönü Cd. Okur Sk. 20 Kozyatağı 34742 İstanbul
TURKEY
irfan.guney@acibadem.edu.tr

NEVZAT ONAT

Vocational School of Technical Studies Electrical Programme
Marmara University
Göztepe Kampüsü, Kadıköy 34722 İstanbul
TURKEY
nonat@marmara.edu.tr

Abstract: - In this study, technological developments and market tendencies in photovoltaic cell (PV) industry are investigated. The increasing energy demand and decrease in conventional energy resources orientates researches to be in tendency to continuously increase the output of alternative energy resources. Today, crystal silicon cells significantly dominate tendencies in PV Cell market with their converting outputs exceeding 20% in small areas. However, a PV panel with silicon crystal is very expensive. To increase output efficiency by decreasing costs of PV cells and modules, nanotechnology approaches are very important. Nanomaterials that used in PV cell production, absorb sunlight better, increase the energy transformation and cheaper than other materials but require special fabrication fixtures. PV cell market is dominated by Japan and Germany. Installation tendencies are become dense on grid-connected systems. Although the costs of PV module per watt generally follow a horizontal route, system installation costs decrease regularly.

Key-Words: - Silicon PV Cells, Nanotechnology, Thin Film, Dye-Sensitized, Efficiency, İnstallation Cost.

1 Introduction

The aim of contemporary energy policy is mainly decreasing the consumption of primary power sources while keeping the growing energy production. Consequently the development and research is focused on increasing the efficiency of energy systems and integration of renewable power sources into the energy production [1].

Photovoltaic (PV) cell was firstly designed and produced at Bell laboratory in 1955. From that date until today, many researches have been made on PV cells and considerable improvements have been obtained in respect of both design and operating performances [2]. Studies on PV generate systems are actively being promoted in order to mitigate environmental issues such as the green house effect and air pollution. In developing nations, the PV generate system is expected to play an important role in total electrical energy demand, and solar photovoltaic energy has gained a lot of attention because it is renewable, friendly to the environment, and flexible for installation [3].

The solar cell is a semiconductor device that converts the solar insolation directly to electrical energy. The cell is a non-linear device and can be represented by the $I - V$ terminal characteristics, or by an approximate electrical equivalent circuit as shown in Fig. 1.

The cells are connected in series and in parallel combinations in order to form an array of the desired voltage and power levels. Fig. 2 represents the $I - V$ and $P - V$ characteristics of the solar-cell generator for five insolation levels (in percentages).

The $I_g - V_g$ equation of the solar cell generator, which consists of N_s cells in series and N_p cells in parallel, is given by:

$$V_g = I_g R_s \frac{N_s}{N_p} \ln\left(1 + \frac{N_p I_{ph} - I_g}{N_p I_0}\right) \qquad (1)$$

$$I_g = I_{ph} - I_0\left(e^{qV_g/kT} - 1\right) \qquad (2)$$

Where, I_{ph} is cell photocurrent (amps), proportional to the insolation; I_0 is cell reverse saturation current; R_s is cell series resistance; $q = 1.602 \cdot 10^{-19} C$ is electron charge, $k = 1.3806 \cdot 10^{-23} J/K$ is the Boltzmann's constant; and T is absolute temperature [4], [5].
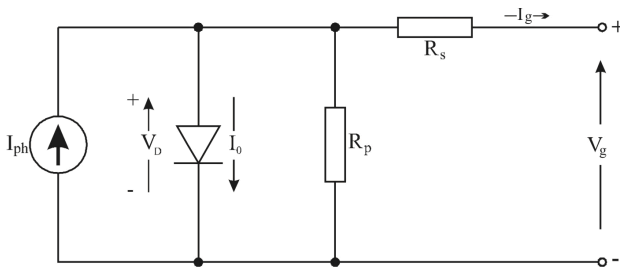

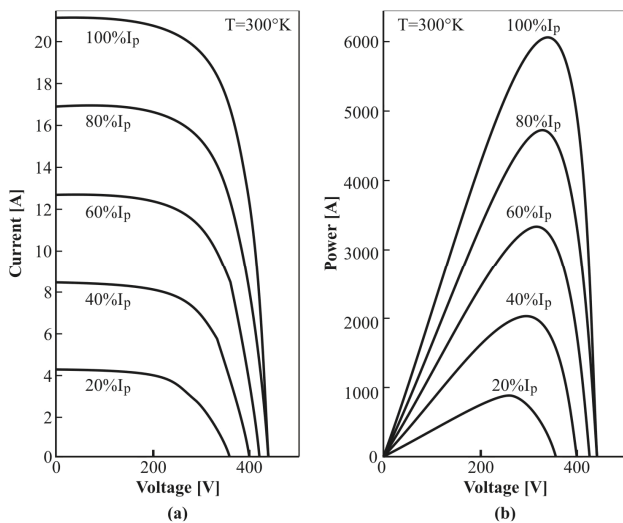Fig. 1 Photovoltaic cell equivalent circuit

Fig. 2 (a) $I - V$ and (b) $P - V$ Characteristics of a photovoltaic cell

Fig. 2 shows that the PV cell has both a limiting voltage and a limiting current. Hence, the cell is not damaged by operating it under either open circuit or short circuit conditions. To determine the short circuit current of a PV cell, simply set $V_g = 0$ in the exponent. This leads $I_{SC} = I_{ph}$. To a very good approximation, the cell current is directly proportional to the cell irradiance. Thus; if the cell current is known under standart test conditions, $G = 1 \frac{kW}{m^2}$ at AM1.5, then the cell current at any other irradiance, G, is given by

$$I_{ph}(G) = \frac{G}{G_0} I_{ph}(G_0) \qquad (3)$$

To determine the open circuit voltage of the cell, the cell current is set to zero and equation (2) is solved V_{OC}, yielding the result,

$$V_{OC} = \frac{kT}{q} \ln \frac{I_{ph} + I_0}{I_0} \cong \frac{kT}{q} \ln \frac{I_{ph}}{I_0} \qquad (4)$$

Since normally $I_{ph} \gg I_0$. For example if the ratio of photocurrent to reverse saturation current is 10^{10}, using a thermal voltage (kT/q) of $26mV$, yields $V_{OC} = 0,6V$. Note that the open circuit voltage is only logarithmically dependent on the cell illumination, while the short circuit current is directly proportional to cell illumination.

The maximum power point may also be determined by differentiating the cell power equation and setting the result equal to zero. After finding the cell power equation is satisfied, and checked to verify that this voltage represents a maximum, maximum power point is known. The maximum power point is also readily found by simply plotting cell power versus cell voltage, as shown in Fig. 2. If I_m and V_m represents the cell current and voltage at maximum power respectively, then the cell maximum power can be expressed as,

$$P_{max} = I_m \cdot V_m = FF \cdot I_{SC} \cdot V_{OC} \qquad (5)$$

Where FF is defined as cell "fill factor". The fill factor is a measure of the quality of the cell. Cell with large internal resistance will have smaller fill factors, while ideal cell will have a fill factor of unity. Note that a unity fill factor suggests a rectangular $I - V$ characteristic. Although a real cell does not have a rectangular characteristic, it is clear that it has a region where its operation approximates that of an ideal voltage source and another region where its operation approximates that of an ideal current source [6], [7]. An empirical expression for the fill factor is

$$FF = \frac{V_{OC} - \frac{kT}{q} \ln\left[\frac{qV_{OC}}{kT} + 0.72\right]}{V_{OC} + \frac{kT}{q}} \qquad (6)$$

The most important figure of merit for a photovoltaic cell is its power conversion efficiency (η), which is defined as

$$\eta = \frac{P_{\max}}{P_{in}} = \frac{FF \cdot V_{OC} \cdot I_{SC}}{P_{in}} \qquad (7)$$

The incident power (P_{in}), is determined by the properties of the light spectrum incident upon the PV cell.

Using these figures of merit, the properties of a good (efficient) solar cell can be ascertained. From equation (7), it is clear that an efficient solar cell will have a high short circuit current, a high open circuit voltage, and a fill factor, as close as possible to 1. As seen in equation (4), the open circuit voltage is logarithmically proportional to the cell photocurrent current (I_{ph}) and to the reciprocal of the reverse saturation current (I_0). Therefore, reducing the saturation current will increase the open-circuit voltage. From equation (6) it is clear that increasing V_{OC} will increase the fill factor. Thus, the design and the operation of an efficient solar cell have two basic goals:

1. Minimization of recombination rates throughout the device.
2. Maximization of the absorption of photons.

It is evident that, despite the apparent complexity of the expressions describing the operation of solar cells, the basic operating principles are easy to understand. Electron–hole pairs are created inside the solar cell as a result of absorption of the photons incident on the solar cell from the sun. The objective is to collect the minority carriers before they are lost to recombination [8].

Most PV systems are used for direct current (DC) electrical appliances because the current produced by a PV cell is basically of the DC type. However, DC electrical appliances are rarely found in everyday usage, and, moreover, it is not worthwhile converting existing alternating current (AC) electrical appliances for a PV power supply. Instead, an inverter is added to the PV system in order to convert the DC generated by the PV modules into AC type suitable for AC appliances [9].

2 Traditional Solar Cells

Very comprehensive studies are being made to decrease the material size and costs and increase the output of crystal, nanocrystal, multicrystal, thin film polycrystal and amorphous PV cells.

In general, it is accepted that reducing the thickness of thin film PV cells below $50mm$ will considerably decrease the material need when compared to silicon layers and have the potential to reach higher productivities. Reduction in thickness of PV cell cause increasing in open circuit voltage. However, crystal cell technology gives better response to cell performance and demands depending on costs when compared to other cell production systems [10], [11].

2.1 Mono or Multi-Crystalline Silicon Solar Cells

Crystalline silicon solar cells and modules have dominated photovoltaic technology from the beginning. They constitute more than 85% of the PV market today, and although their decline in favor of other technologies has been announced a number of times, they presumably will retain their leading role for a time, at least for the next decade.

One of the reasons for crystalline silicon to be dominant in photovoltaics is the fact that microelectronics has developed silicon technology greatly. On the one hand, not only has the PV community benefited from the accumulated knowledge but also silicon feedstock and second-hand equipment have been acquired at reasonable prices [8]

SunPower has reported a silicon panel solar cell with at least 20% output having better life, thickness and compatible price. The wide tolerance provided by silicon panel in respect of thickness and resistance facilities production of the silicon from ingot and rapidly decreases the cost of silicon panel so the production cost of cell. Production of crystal solar cells moves to Multi-Silicon from Mono-Silicon to decrease the defects in crystal structure and the metal contamination [10].

2.2 Thin-Film PV Cells

The thin film technology provides significant advantages in PV cells in respect of high output and economical price, when the indium and gallium elements are used. In production of such cells, to obtain hard and bendable flexible structure, ink-base non-vacuumed production techniques are used. In this system, copper, indium and gallium oxides in nanoparticle state are coated with molybdenum or nonconductive layer. While polyimide coating increases the cell output in rate of 8.9%, molybdenum coatings ensure 13% and glass coatings 13.6% output increase.

2.3 Multi-Junction Concentrator PV Cells

Photovoltaic (PV) concentrators use lenses or mirrors to concentrate sunlight onto PV cells. This allows for a reduction in the cell area required for producing a given amount of power. The goal is to

significantly reduce the cost of electricity generated by replacing expensive PV converter area with less expensive optical material. This approach also provides the opportunity to use higher performance PV cells that would be prohibitively expensive without concentration. As a result, concentrator modules can easily exceed 20% energy conversion efficiency [12].

Development of silicon collector cells began at the end of 1980's. Recently, Amonix has undertaken commercial development attempts of collector cells. The highest cell output reported by Amonix is 27.5% under 122.4 suns. Multi-junction cell producers have obtained cell output exceeding 40% with local collector applications [10], [13].

2.4 Amorphous Silicon/Silicon Hetero-Junction Cells

High output PV cell production with silicon hetero-junction (SHJ) for temperatures under 150°C contains an attractive structure. By using the thin amorphous silicon plates combined with hydrogen as emitters or rear contacts of such cells, the output is increased to 17.5%. By combining the rear contacts of silicon material combined with hydrogen with -p- and -n- type silicon plates, the structure of double hetero-junction cells is developed and the output is increased to 18.2%. These contacts operate reliable at temperatures above 250°C [14].

2.5 Dye-Sensitized PV Cells

Dye-sensitized PV cells (DSPVCs) are a relatively new alternative energy source. Since first reported in 1991, there has been much research interest due to the lower material and processing costs relative to the traditional PV cells. The DSPVC works on a different basis from the silicon PV cells, in which the semiconductor layer is simultaneously the light absorber and the site of the charge separation, which gives rise to the electric current under illumination. In the DSPVC these functions are separated [15].

A DSPVC comprises a nanocrystalline TiO_2 modified with a dye fabricated on transparent conducting oxide, a platinum counter electrode, and an electrolyte solution with a dissolved iodide ion/tri iodide ion redox couple between the electrodes (Fig.3).

In DSPVCs transport of photo generated electrons in a polycrystalline film of randomly connected oxide nanoparticles occurs by trap-limited diffusion. The dye monolayer in the cell is the light sensitive component that photo catalyzes incident light via a process that mimics the role of chlorophyll in photosynthesis. The charge separation is facilitated by other components in the

cell, the semiconductor and the electrolyte. The semiconductor facilitates the negative charge path, while the positive charge travels through the electrolyte. The open circuit voltage is defined as the difference in potentials of the red ox electrolyte and the Fermi level of the semiconductor. But this is slow and limits carrier collection efficiency, especially red wavelengths. However, for practical application, a DSPVC module with size 50x50mm for aperture area $26.5cm^2$ has achieved cell efficiency of 6.32% [10], [14].
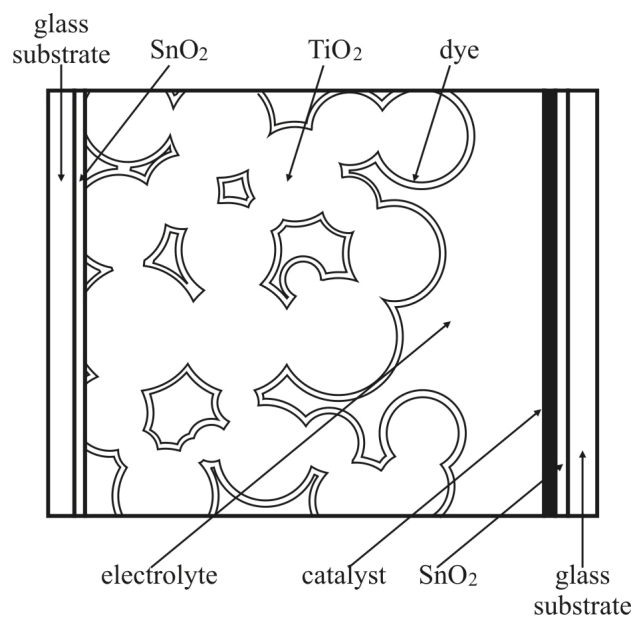

Fig. 3 Structure of dye-sensitized PV cell

3 Nanotechnology Approaches in PV Cell Productıon

Nanotechnology is the arrangement of small structures (about in size of atom) without exemption in a manner serving to a commercial purpose. In other words, operations such as treatment, measurement, modeling and arrangement realized on materials in sizes smaller than $100 nanometers$ are qualified as nanotechnology studies.

The field of nanotechnology is one of the most popular areas for current research and development in basically all technical disciplines. This obviously includes polymer science and technology and even in this field the investigations cover a broad range of topics [16], [17]. Various areas where Nanoscience and Nanotechnology (N&N) are expected to have a significant impact on energy and environmental systems are shown in Table I [18].

With the Nanotechnology Research and Development (R&D) Act signed on December 3, 2003 in America, the public resources to be used in

nanotechnology researches in 4-year period starting from 2005 were determined. Total amount of the resource to be used for 4 years is milliard $3.68. Table II gives distribution of the source within institutions. As it can be seen in the Table II, the USA Government considers that the researches to be made on nanotechnology will be used in very different fields from defense to energy, from health to agriculture [19].

Table I Application areas of nanotechnology

Area			Nanoscience and Nanotechnology aspects
Energy sources	Renewable and/or unlimited	Solar — Solar thermal	Materials
		Photovoltaic	Light harvesting, materials
		PEC, solar hydrogen	Light harvesting, materials, catalysis
		Solar power satellites	Materials
		Wind	Materials
		Wave	Materials
		Hydro	Materials
		Biomass	Catalysis
		Nuclear fusion	Materials, phase (fuel) separation
		Geothermal	Sensors, materials
		Gravitational	Materials
		Extraterrestial feedstock	Materials
	Nuclear fission		Materials, phase (fuel) separation, nanofluids
	Non-renewable	Oil	Catalysis, materials, sensors
		Gas	Catalysis
		Coal	Catalysis
		Unconventional fossil fuels	Catalysis
Energy storage	Water dams		Materials
	Super giro, pneumatic		Materials
	Hydrogen storage		Materials, catalysis, kinetics
	Batteries		Materials
	Supercapacitors		Materials, nanolayered stuructures, electrolytes
Energy conversion	Combustion engines		Materials, diagnostics
	Turbines		Materials, diagnostics
	Fuel cells		Catalysis, diagnostics, electrolytes
	Magneto-hydrodynamic generators		Materials
	Thermo/piezoelectric materials		Nanolayered stuructures
Energy use	Industrial/mining		Sensors, phase separation
	Residential		Non-thermal light sources, materials (smart windows), nanofoams
	Transportation		Materials
Emission cleaning	Gas/air		Catalysis
	Water		Catalysis

Table II Nanotechnology research budgets of USA Government

	2005	2006	2007	2008
Ministry of Defense National Science Foundation	385	424	449	476
Ministry of Energy Ministry of Health and Human Services National Institute of Health	317	347	380	415
National Institute of Standarts and Technology	68,2	75	80	84
NASA	34,1	37,5	40	42,3
Ministry of Agriculture Environment Protection Agency Ministry of Homeland Security	5,5	6,1	6,4	6,8
Annual Total (million $)	809,6	889,6	955,4	1024,1
TOTAL (million $)	3678,9			

The nanotechnology oriented to semiconductors and optoelectronic devices has permitted the research field on semiconductor devices and new materials towards a new era in the study of inorganic semiconductor materials to emerge; there is an opportunity to improve all the physico-chemical characteristics of the semiconductors used principally in photovoltaic applications. The improvements of charge carrier generation/recombination ratio and charge transfer mechanisms are two of the most important challenges for the technology applied to nanostructured semiconductors design [16], [20]. The selective absorption properties of nanomaterials had attracted a main interest in the1980s for application to solar energy harvesting. Such optical properties are in particular shown by metallic particles or fibers dispersed in a ceramic matrix due to the excitation of the plasma resonance of the free electrons. The increasing demand for the development of cheap and renewable energies has led to a new interest for nanomaterials. To increase the energy transformation, in production of third generation PV cells, structures from nanotechnology product that absorbs the sun light better is emphasized. Quantum dots, nanotubes and last generation PV cells having a hot carrier structure can be given as an example [21], [22].

3.1 Nanotubes

Carbon nanotubes are the tubes in molecular measure containing hexagonal grid carbon having considerable mechanical and electrical properties. Structure of a nanotube can be defined as vectoral. In each tube, there is "n" number line and "m" number column (Fig. 4). Nanotubes may be metallic or semi-conductive depending on their structures. Electronic specifications change depending on diameters and n, m values.
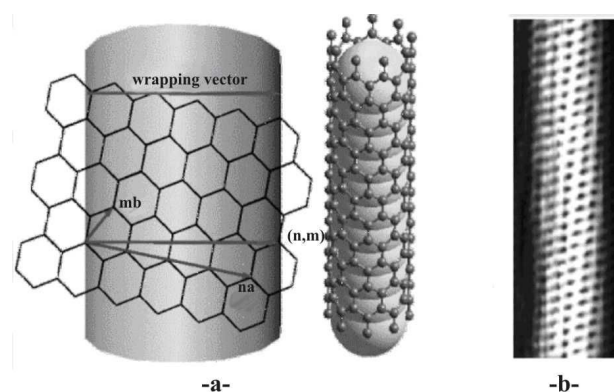

Fig. 4 (a) Structure and (b) scanning tunneling microscope image of nanotube

There are two nanotube models; single-walled (SWNT) and multi-walled (MWNT) carbon tubes.

The single-walled model is in cylinder tube shape consists of a single layer (Fig. 5). In multi-walled nanotubes, there are more than one concentric cylinder inside of each other (Fig. 6).
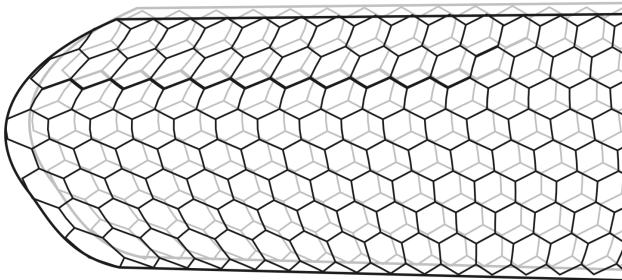

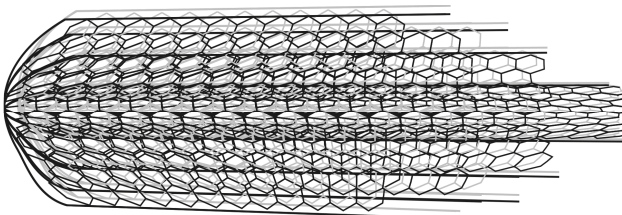Fig. 5 Single-walled nanotube model

Fig. 6 Multi-walled nanotube model

In photovoltaic cell technology, electric energy production can be realized by coating the tubes in nanometer diameter with a special p-n combined semi-conductive material and increasing the existing area for electric production.

Recently, nanotubes are being used as electrodes in production of productive and flexible structured PV cells. To increase the output and decrease the cost, heterogeneous PV cells with molecular structure is being produced by compact the single walled carbon nanotubes containing a polymer and dying matter among the electrodes [10].

3.2 Quantum Dots
Quantum dots is a special semi-conductor model consists of combination of periodic groups of materials molded in various forms, in size of nanometer and having a band gap of which energy levels can be adjustable. Wider dots will emit or absorb solar radiation in longer wave lengths. PV cells made of semi-conductors having a bigger band gap will give higher output voltage by absorbing more energy loaded photon.

On the other hand, a cell having a smaller band gap will ensure higher current at low output voltage by keeping more photons forming the red end of solar radiation.

Recently, researches focus on increasing the output of photovoltaic transformation in the third generation cells produced with quantum particles. For this purpose, a three-dimension design that

ensures powerful electronic combinations among quantum dots is made and models that are capable of producing electric energy with high output voltage and realizes collection and conveyance of high energy beams for a long time are developed.
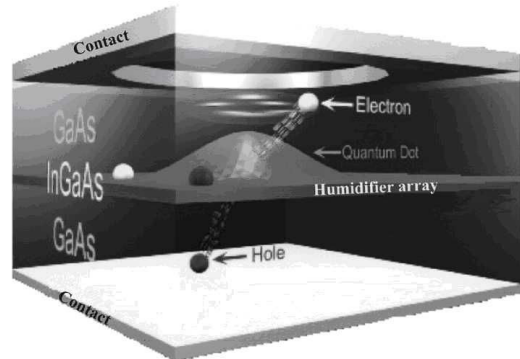

Fig. 7 Structure of PV cell with quantum dots principle

A PV cell made of gallium-arsenic elements is given in Fig. 7. Though the cell structure made of such elements has a high output advantage, it is more expensive than the silicon semi-conductive designs.

In silicon base quantum dotted cells, generally silicon-silicon dioxide (Si-SiO$_2$), silicon-silicon carbide (Si-SiC) or silicon-silicon nitrite (Si-Si$_3$N$_4$) compounds are used. In Fig. 8, differences between voltage band widths of each three structures are given [10].
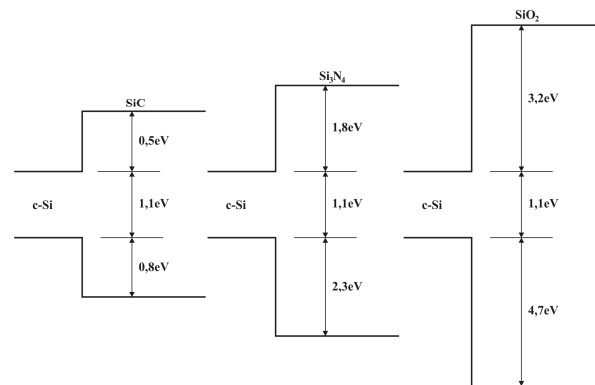

Fig. 8 Bulk band alignments between crystalline silicon and its carbide, nitride, and oxide

3.3 Hot Carrier PV Cells
Today, in electric production technology from sunlight, hot carrier PV cells are considered as the newest approach model.
This system depends on the basis of detaching from the semi-conductor of high energy electrons and cavities formed by light in the semi-conductive

element by using elective energy binds without transforming their extra energies to heat (Fig. 9).
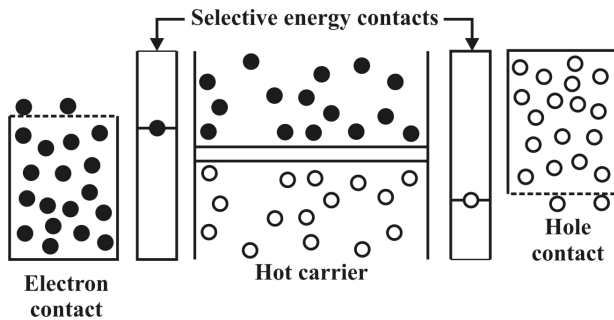

Fig. 9 Structure of hot carrier PV cell.

Ross and Nozik reported the output limit of these systems as 66% [23]. This rate is 52% better than an ideal traditional PV cell system and 33% better than the systems depended on quantum dot principle. According to these researches, this high output realizes because of rarely seen adverse transformation in negative value that ensures a high Carnot output, decreases radiation losses, activates with a small electric energy and is made of heat of hot carriers.

In that approach, it is stated that high energy carriers flowing from selective energy bounds move more rapidly than various non-flexible dispersion acts that cause heating of molecular structure (Fig. 10)
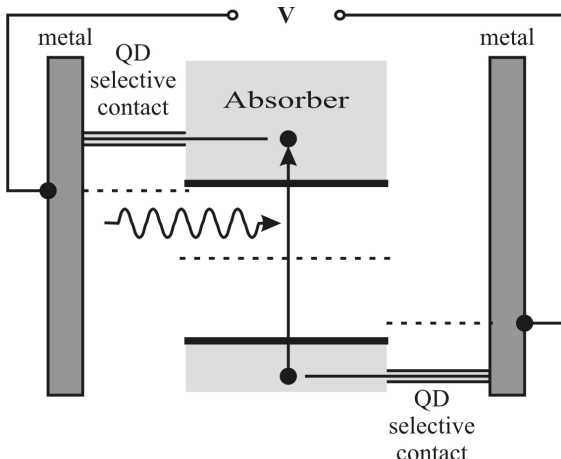

Fig. 10 Collecting of hot carriers before thermalization

However, to eliminate the problems experienced in calculation of current-voltage characteristics of hot carrier PV cells with conservation of mass law (number of electrons detached by bounds is equal to difference between the absorbed and dispersed photons), researches accept that stroke ionization occurs in high energy carriers above $0.5eV$ open circuit band width [10].

3.4 PV Cells for Space Investigations

In the mid 1950s, the development of single-crystal photovoltaic cells based on Si, as well as GaAs, had reached solar conversion efficiencies as high as 6%. By 1958, small-area silicon solar cells had reached an efficiency of 14% under terrestrial sun-light. These accomplishments opened the door to the possibility of utilizing solar power on board a spacecraft. On March 17, 1958 the world's first PV-powered satellite was launched, Vanguard I. It carried two separate radio transmitters to transmit scientific and engineering data concerning, among other things, performance and lifetime of the 48 p/n silicon PV cells on its exterior. The battery powered transmitter operated for only 20days, but the PV cell powered transmitter operated until 1964. The PV cells used on Vanguard-I were fabricated by Hoffman Electronics for the US Army Signal Research and Development Laboratory at Fort Monmouth. In 1961, many of the staff from the silicon cell program at Fort Monmouth transferred to the National Aeronautics and Space Administration (NASA), Lewis Research Center (now Glenn Research Center) in Cleveland, Ohio. From that time to the present, the Photovoltaic Branch at Glenn has served as the research and development base for NASA's solar power needs. Impressed by the light weight and the reliability of PV cells, almost all communication satellites, military satellites, and scientific space probes have been PV-powered.

It should be noted that the history presented here focuses on the United States space program. NASA was created in 1958; the Institute of Space and Astronautically Sciences (ISAS) and the National Space Development Agency (NASDA) in Japan were created in 1965 and 1969, respectively; the European Space Agency (ESA) was created in 1975 by the merger of the European Organization for the Development and Construction of Space Vehicle Launchers (ELDO) and the European Space Research Organization (ESRO), which had begun in the early sixties. There are notable achievements in photovoltaic from these multiple agencies [8].

Recently, researches from the NASA Glenn Research Center and Rochester Technology Institute (RIT) make intensive efforts to develop space PV cells in which the quantum dots (QDs) and single-walled carbon nanotubes (SWNTs) are used. The theoretical results obtained as a result of such researches indicate that using of zero size conductors on three-dimensional surfaces in a "pn" combination PV cell structure causes considerable output increase. The technological developments obtained from thin film layer cells by using polymer

materials will be able to be provided in using of one-dimension quantum structures such as carbon nanotubes that contribute in carbon detaching as well as in energy transmission. The carbon nanotube polymer PV cells are produced with poly3octylthiophene (P3OT) in rate more than 95%. The single-walled carbon nanotubes produced by using laser technology ensures an open circuit voltage more than 1V and higher PV cell output in comparison to $0,12mA/cm^2$ short circuit currents. As a result of diffusion of single-walled nanotubes in P3OT, electrical conductivity and optic absorption ability of a polymer material increase considerably when compared to natural polymers. This type of polymer materials can display the high electron gravity and electrical conductivity together as seen in Fig. 11.
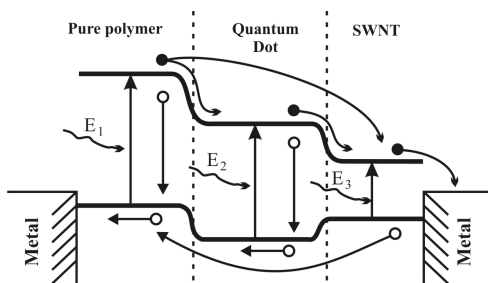

Fig. 11 Energy level diagrams of polymer, QD and SWNT PV cells.

Consequently, researchers focus on four basic problems experienced in development of polymer PV cells; photon absorption, electron dispersion, electron detaching and energy carrying [10].

4 Tendencies and Costs

PV as a technology and a business has just surpassed annual sales of 1GW and U.S.$10B. Worldwide shipments have been growing above 25-30% annually for the past decade. PV is a real business now and should continue to exhibit such substantial annual increases for some time to come. Much of this growth has been the result of government incentives, mainly in Japan and in Germany. Both these governments have shown that policies make a difference using quite different approaches. The market stimulation in Japan has been based on cash subsidies, initially buying down the price to the consumer. Starting in 1994 with a 50% rebate, this program has followed its design to gradually phase down the government portion as the price for the PV system decreased. This coming year, the programs success is indicated by the more than 140,000 installations and reaching the point that no subsidies are needed in their electricity price

market. On the other hand, Germany introduced a "feed-in tariff" in 2000 that offers solar PV users a guaranteed "Euro per kWh" over a 20-year period, with each year the guaranteed price is reduced by 5%. With the availability of low-interest loans, the German markets have heated from less than 20MW/year to above 150MW/year currently. The cost is spread over the entire electricity user rate base so that utilities are not negatively impacted and the government does not have to appropriate the funds annually.

The successes of these policies sometimes overshadow another important component technology advancement. The 18–22U.S.cents/kWh that has been reached also required a progression of substantial and creative research and development (R&D) improvement in materials, devices, fabrication, characterization, and processing, leading better device performance and reliability, and lowered systems costs that the "policies" have leveraged. This electricity price breaches into some electricity markets. But it is still too high for the next wave of grid-tied applications (consumer side of the meter prices) and almost an order or magnitude too high for wholesale (central utility) generation. To tip this technology to its next level—building first multi-GW markets toward the terawatt levels, and manufacturing plants to hundreds of megawatts then perhaps the GW annual capacities, PV technology requires even more creativity, science, and engineering to meet the growing and diversified technical and consumer demands [8].

According to the report of International Energy Agency (IEA)-Photovoltaic Power Systems Program (PVPS), Japan realized 22% of the world's PV cell production in 2007. PV cell production of 1905MW in 2006 raise to 2401MW in 2007 and the increase in rate of 21% in a year was realized in PVPS countries. The biggest increase was recorded by Germany with 328MW and by USA with 64MW. Japan realized photovoltaic cell production in power of 923MW in 2007 and it continues its leadership (Fig. 12).
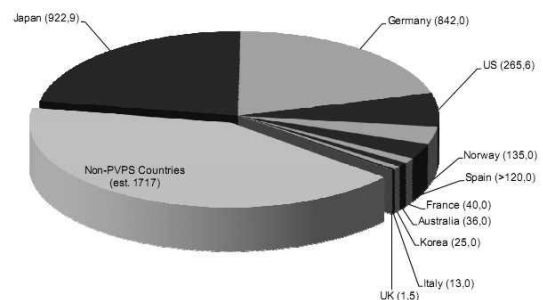

Fig. 12 PV cell production (MW) by country in 2007

While in first years of installation of PV cell systems, mostly stand-alone systems were in demand, today grid connected systems are being preferred (Fig. 13 and Fig. 14).

The installation costs of PV cell system differ greatly among the countries. Besides, very significant differences occur from year to year. For instance, 3.7$/W module cost for Japan in 2003 increased to 5.2$/W in 2005 in rate of 30% (Fig. 15) [24].
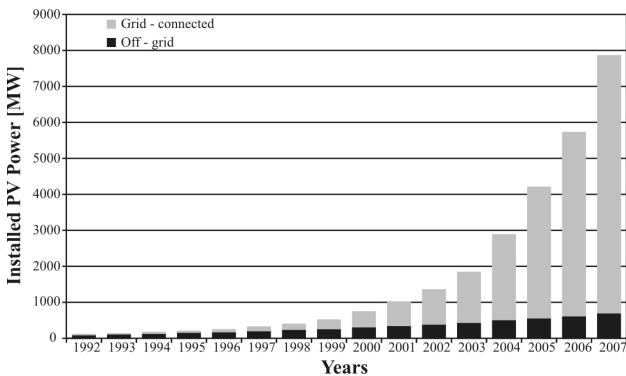

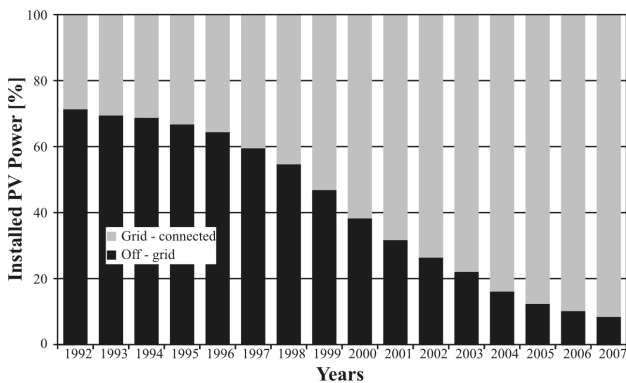Fig. 13 Cumulative installed grid-connected and off-grid PV power in the reporting countries

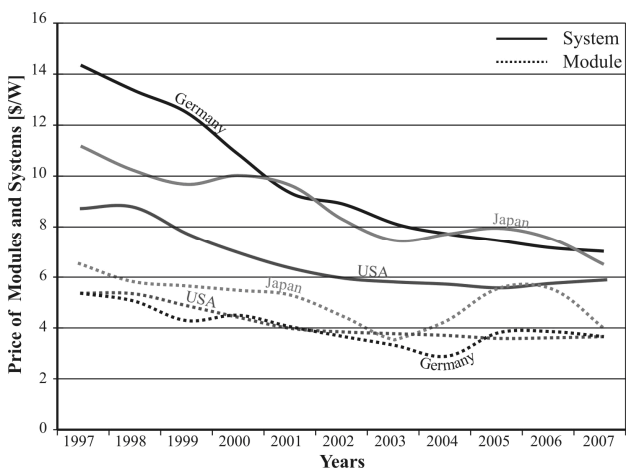Fig. 14 Percentages of grid-connected and off-grid PV power in the reporting countries.

Fig. 15 Evolution of price of PV modules and small-scale systems in USA, Germany and Japan, accounting for inflation effects - Years 1997-2007

5 Conclusions

The solar energy losses can be classified as optic losses resulting from reflection, energy carrying losses caused by bad combination or material quality, heat losses resulting from heating of electrons and optic power losses that occur because of wasting of infrared light in big size. In recent years, crystal silicon technologies became one of the most widely used applications in production of PV cell. Single combination silicon PV cells can be produced in at last 20-25% output interval. Though multi-combination silicon cells are cheaper, their output can only be between 18-22%. The output interval for thin film photovoltaic modules potentially cheaper than crystal structured cells is 9%-%13. Defects and contamination in silicon crystals of such cells both effect the energy transformation and decrease the load carrying life of cell. Defects in size of particulars, placement defects and defects resulting from dust, dirt and rapid cooling must continuously be controlled. The cell output can be increased above 22% depending on defects in production and installation phases.

To increase the energy transformation output, the research and development studies especially focus on hybrid PV cells under nanotechnology that especially quantum dots, nanotubes and hot carriers are used. However, understanding and cognition variations occur in big body production dot of photovoltaic cells. For instance, a cell to be produced by using single-walled nanotubes must be in micrometer sizes. Basic problems for nanotechnology base PV cells contain photon absorption, electron detaching and dispersion and energy carrying that requires special fabrication fixtures. An additional changing in systems that produce traditional PV cell is the requirement of a single energy contact construction between hot carriers in absorber of high energy carrier PV cells and low energy carriers in junctions.

The PV cell market dominated especially by Japan, Germany and USA in the world increasingly expands. The installed power amount is continuously increasing. To speed this increase more is only possible if the production costs of PV cells are decreased and output is increased to compatible levels.

Besides, it is observed that the tendency in installation of PV cell systems move to network connected structures. The costs of PV cell modules per watt generally follow a horizontal route. On the other hand, the installation costs of PV systems have decreased in rate of 50% since 1996. As long as nanotechnology product materials can be used in

production of such cells, significant developments will be obtained in respect of both cost and output.

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